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# Radio Tag Retention and Tag-Related Mortality among Adult Sockeye Salmon

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*Abstract.*—Tag retention and tag-related mortality are concerns for any tagging study but are rarely estimated. We assessed retention and mortality rates for esophageal radio tag implants in adult sockeye salmon *Oncorhynchus nerka*. Migrating sockeye salmon captured at the outlet of Lake Clark, Alaska, were implanted with one of four different radio tags (14.5 × 43 mm [diameter × length], 14.5 × 49 mm, 16 × 46 mm, and 19 × 51 mm). Fish were observed for 15 to 35 d after tagging to determine retention and mortality rates. The overall tag retention rate was high (0.98; 95% confidence interval [CI], 0.92–1.00; minimum, 33 d), with one loss of a 19-mm × 51-mm tag. Mortality of tagged sockeye salmon (0.02; 95% CI, 0–0.08) was similar to that of untagged controls (0.03 [0–0.15]). Sockeye salmon with body lengths (mid-eye to tail fork) of 585–649 mm retained tags as large as 19 × 51 mm and those with body lengths of 499–628 mm retained tags as small as 14.5 × 43 mm for a minimum of 33 d with no increase in mortality. The tags used in this study represent a suite of radio tags that vary in size, operational life, and cost but that are effective in tracking adult anadromous salmon with little tag loss or increase in fish mortality.

All tagging studies assume that (1) tags are retained for the duration of observation and (2) tagged individuals accurately represent the population under study. It is generally difficult, if not impossible, to confirm either assumption in species that are cryptic or elusive enough to merit radio tagging. In the case of wild fish, radio-tagged individuals are rarely recovered, making it difficult to estimate rates of tag loss and fish mortality. Such estimates are essential to determine sample sizes that compensate for tag loss and, if rates vary with tag size or type, to select the tag with the greatest probability of retention and fish survival.

Esophageal implant tags do not impair feeding ability or reduce the swimming performance of juvenile coho salmon *Oncorhynchus kisutch* (Moser et al. 1990) or alter the behavior and dominance rank of or cause infection in rainbow trout *O. mykiss* or white perch *Morone americana* (Mellas and Haynes 1985). Such tags require the shortest handling time, anesthesia, and revival time of the available tagging techniques but are prone to loss through regurgitation. Esophageal implant tags may make fish visibly uncomfortable (e.g., increased flaring of the opercular plates and coughing) and delay or alter the migration patterns of chinook salmon *O. tshawytscha* (Gray and Haynes 1979). Retention rates vary widely by species and time (Table 1). Tag retention was 100% among adult migrating sockeye salmon (tracked <2 d; Groot et al. 1975) and Atlantic salmon *Salmo salar*, (tracked 23–107 d; Gerlier and Roche 1998) but was zero among rockfishes *Sebastes* spp., (tracked < 1 d; Matthews et al. 1990) and only 20% among rainbow trout (21-d trial; Mellas and Haynes 1985). Tagging-induced mortality appears to be low with this technique. Esophageal implant tags did not increase mortality among rainbow trout (21-d trial, $N$ = 15 per treatment; Mellas and Haynes 1985), and only 8% of sauger *Stizostedion candense* died within 2 d of tagging ($N$ = 164; Olson et al. 1990).

Esophageal tagging is considered the best tagging method when regurgitation is not prevalent (Mellas and Haynes 1985) and is the preferred method among those studying adult salmonids during migration or spawning (Burger et al. 1985, 1995; Eiler 1990; Ruggerone et al. 1990). However, there is a lack of information on rates of tag retention and tagging-induced mortality for sockeye salmon. Field studies typically do not control for natural mortality levels and are often unable to differentiate between dead tagged fish, tags that

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TABLE 1.—Rate of retention of esophageal implant tags among species in both laboratory and field settings.

| Species | $N$ | Retention rate (%) | Trial duration (d) | Setting | Reference |
|---|---|---|---|---|---|
| Sockeye salmon | 21 | 100.0 | $<2$ | Field | Groot et al. 1975 |
| Rainbow trout | 15 | 20.0 | 21 | Lab | Mellas and Haynes 1985 |
| White perch | 25 | 92.0 | 45 | Lab | Mellas and Haynes 1985 |
| Rockfish | 5 | 0.0 | $<1$ | Lab | Matthews et al. 1990 |
| Sauger | 193 | 88.1 | 7 | Lab | Olsen et al. 1990 |
| Atlantic salmon | 27 | 85.2 | 21–90 | Field | Smith 1998 |
| Atlantic salmon | 18 | 100.0 | 23–107 | Field | Gerlier and Roche 1998 |
| Brown trout[a] | 8 | 33.3 | 9–176 | Field | Gerlier and Roche 1998 |

[a] *Salmo trutta.*

have been expelled, and fish that are sedentary or at depth (Groot et al. 1975; Eiler 1990; Olson et al. 1990; Gerlier and Roche 1998). We quantified the rates of tag retention and mortality for adult sockeye salmon implanted with esophageal radio tags of a range of sizes.

## Methods

*Fish collection and holding.*—Adult sockeye salmon were captured at the outlet of Lake Clark, Alaska between July 14 and 16 in 1999 ($N = 30$), 2000 ($N = 29$), and 2001 ($N = 30$). All fish were in prespawning condition (bright silver skin coloration and not emitting eggs or milt) at time of capture. Fish were captured with a monofilament gill net (61 m long $\times$ 3.7 m deep, with 14-cm mesh size) in 1999 and with a nylon seine (61 m long $\times$ 2.4–3.7 m deep, with 10.2-cm mesh size) in 2000 and 2001. Fish were divided equally between net-pens (with 15 fish in each of two pens in 1999 and 10 fish in each of three pens in 2000 and 2001) and allowed to acclimate at least 24 h prior to tagging. Capture nets were changed and fish density in the pens decreased between 1999 and 2000 due to concerns about size selectivity and stress to captured fish. Net-pens (1.2 $\times$ 1.2 $\times$ 1.8 m) composed of a fine black mesh stretched over a 2.5-cm-diameter polyvinyl chloride pipe frame were anchored in approximately 1.5 m of river water. Water flow through the mesh followed the regular current.

*Experimental treatments.*—Four tag sizes were tested (Table 2), representing the range typically used in studies of adult anadromous salmonids (Burger et al. 1995; Gerlier and Roche 1998; Smith et al. 1998). Dummy tags that directly mimic the dimensions, weight, and materials of actual radio tags were used due to cost constraints (US $25 per dummy tag versus $201 per radio tag). Three of the dummy tags are manufactured by Lotek Engineering (Newmarket, Ontario) and are composed of a biologically inert polypropylene copolymer with a 44-cm stainless steel, Teflon-coated whip antenna. The largest tag is manufactured by Advanced Telemetry Systems (Isanti, Minnesota) and is composed of a biologically inert electrical resin with a 30.5-cm stainless steel, nylon-coated whip antenna.

Within years, fish were tagged by the same person, on the same day, and within 48 hours of their capture. Fish were anesthetized (70 mg/L clove oil; Woody et al. 2002) and their sex and body length (mid-eye to tail fork) recorded. Dummy tags were coated with glycerin and implanted in the fish's stomach via the esophagus with a Plexiglas plunger (Monan et al. 1975). A Peterson disk tag pinned through the dorsal musculature of each fish (radio-tagged and control) coded for individuals and their treatments. Fish of each treatment were divided among all net-pens to avoid confounding a treatment effect with an enclosure effect. Treatments were applied to fish in a staggered fashion

TABLE 2.—Dimensions, weight, transmission times, and manufacture information for radio tags tested on wild sockeye salmon at Lake Clark, Alaska.

| Diameter (mm) | Length (mm) | Volume ($cm^3$) | Weight in air (g) | Mean operational life (d) | Manufacturer | Model |
|---|---|---|---|---|---|---|
| 14.5 | 43 | 7.1 | 10.9 | 263 | Lotek | MCFT-3B |
| 14.5 | 49 | 8.1 | 12.9 | 380 | Lotek | MCFT-3E |
| 16 | 46 | 9.2 | 15.6 | 769 | Lotek | MCFT-3A |
| 19 | 51 | 12.5 | 20.8 | 1,183 | ATS | F1845 |

TABLE 3.—Mid-eye to tail-fork length and sample size of sockeye salmon from Lake Clark, Alaska, of different tag-size treatments. Values in parentheses are ranges.

| Tag-size treatment or total | Sample size 1999 | 2000 | 2001 | Total | Mean length (mm, ± SD) |
|---|---|---|---|---|---|
| 14.5 × 43 | 10 | 10 | | 20 | 553.7 ± 36.9 (499–628) |
| 14.5 × 49 | | | 10 | 10 | 606.9 ± 29.7 (542–646) |
| 16 × 46 | 10 | 9 | | 19 | 565.1 ± 38.2 (506–632) |
| 19 × 51 | | | 10 | 10 | 613.2 ± 19.2 (585–649) |
| Control | 10 | 10 | 10 | 30 | 576.9 ± 39.2 (511–640) |
| Total | 30 | 29 | 30 | 89 | 588.1 ± 39.8 (499–649) |

to control for the experience level of the technician.

Because logistical constraints precluded testing all tag types simultaneously, two tag types were tested against control fish in each year of the study and different tags were tested in different years (Table 3). Sample sizes were 10 fish per treatment and year, except that only 9 fish were tagged with the 16-mm × 46-mm tag in 2000 due to the loss of an irreplaceable dummy tag. Observations were replicated in a second year (2000) for tags of sizes 14.5 × 43 mm and 16 × 46 mm, yielding overall sample sizes of 20 and 19 fish, respectively. The 14.5-mm × 43-mm tag was fitted with a larger battery in 2001, thereby increasing its dimensions to 14.5 × 49 mm. This tag was then tested against a much larger tag (19 × 51 mm) to better assess whether tag loss and fish mortality increase with tag size.

*Monitoring tag retention and mortality*.—Tag retention and mortality were determined by daily visual checks over 15, 35, and 33 d in 1999, 2000, and 2001, respectively. An antenna protruding from the mouth of the fish confirmed tag retention. The length of the observation period was increased between 1999 and 2000 to reflect the duration of the run and to determine whether retention or mortality would increase over time. Because the tags tested in 1999 were also tested in 2000, every size of tag in this study was observed for at least 33 d. Necropsies were performed on all tagged fish at the close of the observation period or, in the case of mortality, on the day of their death. Necropsies comprised inspection of the stomach and body cavity of each fish for stomach rupture. All fish were still in prespawning condition at the end of the observation period (not emitting eggs or milt) but were exhibiting slight spawning coloration (pink flanks and green head).

*Data analysis*.—One-way analysis of variance followed by Tukey's honestly significant difference test for multiple comparisons was used to compare mean fish body lengths among years. For tags tested in multiple years, two-way analysis of variance was used to compare mean fish body lengths among treatment groups and years. Tag retention and mortality were calculated as binomial proportions, and their 95% confidence intervals were computed according to Zar (1999).

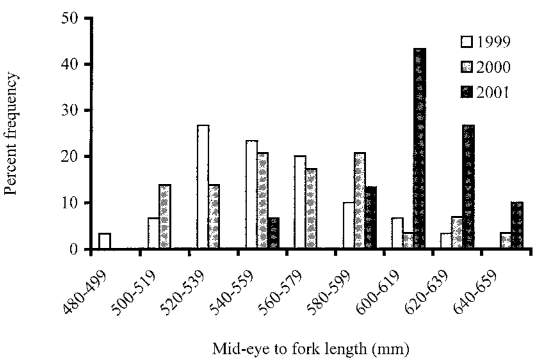


FIGURE 1.—Distribution of sockeye salmon by body length (mid-eye to tail fork), 1999–2001, with all radio tag treatments pooled.

## Results and Discussion

### *Body Length among Years and Treatments*

The sampled sockeye salmon ranged from 499 to 649 mm in body length (mean, 588.1 mm; SD, 39.8 mm; Table 3). Body length varied significantly by year ($F_{2,86} = 28.470$, $P < 0.001$; Figure 1) due to the greater size of the fish in the 2001 return. Mean body length did not differ between fish collected in 1999 and 2000 ($q_{86,2} = 1.17$, $P > 0.05$) but differed significantly among fish collected in each of these years and 2001 (1999 and 2001: $q_{86,2} = 7.05$, $P < 0.05$; 2000 and 2001: $q_{86,2} = 5.82$, $P < 0.05$). Body length also did not differ among fish tagged with 14.5-mm × 43-mm and 16-mm × 46-mm tags in 1999 and 2000 ($F_{2,55} = 0.542$, $P = 0.584$). Thus, these tags were applied to a similar size distribution of fish, and years were pooled within treatments in all comparisons. Be-

TABLE 4.—Rentention of esophageal implant tags and mortality rate of sockeye salmon, Lake Clark, Alaska, by treatment and overall, expressed as means and 95% confidence intervals (CIs).

| Tag-size treatment or total | $N$ | Retention | | Mortality | |
|---|---|---|---|---|---|
| | | Mean | CI | Mean | CI |
| 14.5 × 43 | 20 | 1.00 | 0.86–1.00 | 0.05 | 0.03–0.22 |
| 14.5 × 49 | 10 | 1.00 | 0.74–1.00 | 0 | 0–0.31 |
| 16 × 46 | 19 | 1.00 | 0.85–1.00 | 0 | 0–0.18 |
| 19 × 51 | 10 | 0.90 | 0.61–1.00 | 0 | 0–0.31 |
| Control | 30 | | | 0.03 | 0–0.15 |
| All tagged fish | 59 | 0.98 | 0.92–1.00 | 0.02 | 0–0.08 |
| All treatments | 89 | 0.98 | 0.92–1.00 | 0.02 | 0–0.07 |

cause the 14.5-mm × 49-mm and 19-mm × 51-mm tags were applied only in 2001, they were tested only in the largest fish in the study, while the 14.5-mm × 43-mm and 16-mm × 46-mm tags were tested across a wider range of fish body sizes (Figure 1). The results are applicable to at least the body size range of fish tested for each tag size (Table 3).

### *Tag Retention*

Tag retention was high for all treatment groups. All but one fish ($N = 59$) retained their tags, giving an overall tag retention rate of 0.98 (95% confidence interval [CI], 0.92–1.00; Table 4). Of the 58 fish that retained their tags, 57 did so for the full observation period (15, 35, and 33 d in 1999, 2000, and 2001, respectively), while 1 died after 3 d of observation. The nearly complete overlap of 95% confidence intervals suggests that there is little if any difference in tag retention among treatment groups (Table 4). Thus, tag retention was high for at least 33 d after tagging and was similar among all body lengths and tag sizes tested.

Only 1 of 59 tagged fish regurgitated its tag, and this occurred within 24 h of implantation. The overall retention rate was 0.90 (95% CI, 0.61–1.00) for the 19-mm × 51-mm tag size and 1.00 (95% CI, 0.74–1.00) for all other tag sizes (Table 4). Tag loss may be caused by inappropriate tag shape or size. All tags were cylindrical in shape except the 19-mm × 51-mm tag, which was bottle-shaped and possibly easier to regurgitate. Large tag size relative to fish body size decreases tag retention rates among juvenile coho salmon (Moser et al. 1990) and could have caused the single tag loss that we observed. The fish that regurgitated the tag was one of the smallest in its treatment group (586 mm), while the lost tag was one of the largest used in this study (19 × 51 mm). However, another small fish (585 mm) in this treatment group retained its tag for 33 d.

### *Mortality*

Two premature mortalities occurred during the study, yielding an overall mortality rate of 0.02 (95% CI, < 0.01–0.07; Table 4). One mortality was a male tagged with a 14.5-mm × 43-mm tag that died after 3 d of observation; the other was a female control fish that died after 14 d of observation. Both fish were of medium size (560 and 527 mm, respectively), and the tag size was the smallest tested. No mortalities occurred in 2000 or 2001, and the mean mortality rate among tagged fish ($N = 59$) was low (0.02; 95% CI, < 0.01–0.08) and similar to that of controls (0.03; 95% CI, < 0.01–0.15; $N = 30$; Table 4). Mortality did not differ among tag treatment groups or between tagged and control fish (the 95% confidence intervals overlap nearly completely; Table 4).

The cause of death of the tagged fish is unclear. Necropsy revealed that the fish had a ruptured stomach, but two observations suggest that this mortality was not tagging related. First, two other fish with ruptured stomachs behaved normally, retained their tags, and survived the entire observation period (15 d in 1999 and 35 d in 2000). Second, the death of a control fish suggests that mortality occurred among our study fish regardless of the tagging treatments. Thus, the premature mortality of the tagged fish may have been due to natural causes rather than the tagging procedure.

## Conclusions

Tag dimensions are limiting in the application of esophageal radio tags to anadromous salmonids. Tags of 19.5 × 55.5 mm and 20 × 80 mm cause stomach rupture and mortality among sockeye and coho salmon less than 480 mm in length, while tags of 15.5 × 46.5 mm and 20 × 65 mm allowed tagging of sockeye salmon as small as 405 mm (Burger et al. 1985, 1995; Eiler 1990). The tags tested for this paper represent a suite of commercially available radio tags that are appropriate for studies of migrating and spawning adult salmonids at least 500–650 mm long (from mid-eye to fork). Even when implanted by inexperienced technicians, these tags are retained at high rates over a common range of body sizes with little or no increase in mortality over at least 33 d of observation, a time period greater than the migration and spawning periods of many anadromous salmonids. Our study fish were captured near the end of their spawning migration and held in the river in a suspended state of migration. Therefore, our tag retention and survival estimates should be conservative, but they could still be optimistic for fish with longer spawning migrations or greatly depleted energy reserves at time of tagging. Researchers planning to tag fish smaller than 500 mm or larger than 650 mm or to track fish for extended periods should conduct controlled experiments to assess long-term rates of tag loss and tagging-induced mortality.

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